

THE APPLICATION OF DIGITAL COMPUTERS TO
HIGHWAY LOCATION ANALYSIS

by

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One of the engineer's primary functions is to make decisions. His creative and constructive roles follow the decision-making and are dependent on it. The purpose of this paper is to explore this idea as it applies to highway location and to illustrate the use of mathematical models and high-speed digital computers in solving location problems.

If the engineer is basically a decision-maker then the terms "decision-making" and "the engineering process" are nearly synonymous. In fact, engineering has been defined as simply the use of available information "to determine the best course of action for some human undertaking."⁽¹⁾ Obviously the route from information acquisition and processing to final decision must be a logical one. Figure 1 shows schematically the sequential steps in the engineering process. ⁽¹⁾² The basic steps; search, prediction, evaluation and decision are enclosed in rectangles; the outcome of each step is shown in brackets.

First some goal or objective must be defined for the project. This is usually done on the "executive level" and typically results in objective statements that are somewhat vague (from an engineering viewpoint). The engineer's initial step is to redefine and clarify the goal or goals in his own terms and to reconcile his redefinition with executive's original intention.

Secondly a search is made for feasible alternate solutions that will achieve the desired goals. Many possible solutions may be eliminated intuitively by the experienced engineer. There still remain, in most cases, a great many possibilities. The number of alternatives finally selected for further analysis depends on the time available to the engineer and the relative importance of the project.

Connected with each selected alternative is a set of consequences. These are mostly physical in nature and are normally expressed in terms of cubic yards, miles of roadway, road user costs, etc. Of increasing importance, however, to the present-day highway engineer is a determination of the intangible consequences of his work; i.e. such things as driver comfort and convenience, the appearance of the completed roadway and the social impact of the new road on nearby communities.

¹Numbers in parentheses refer to references listed at the end of the paper.

²Figures 1,2 and 3 were adapted from reference 1.

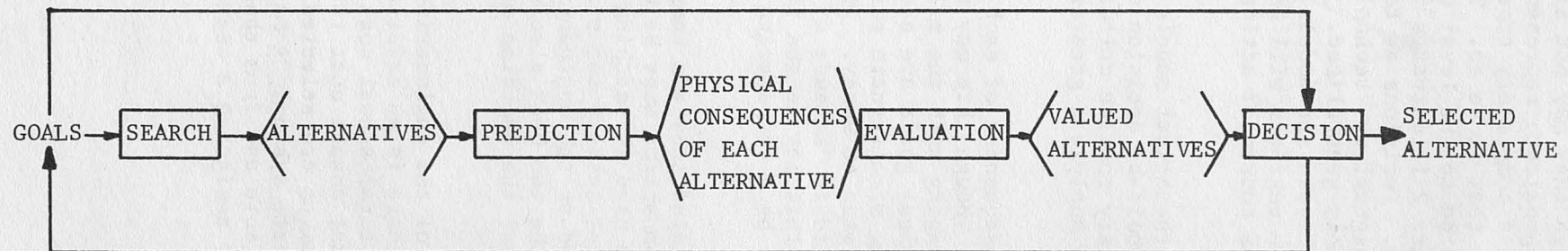


FIGURE 1 - THE ENGINEERING PROCESS

Predicting the consequences of a given engineering action requires the use of mathematical models, though they may not always be labeled as such. A mathematical model is an approximate representation of a portion of the real world. It never is a completely true representation and it is not particularly desirable that it be so. The degree of approximation permitted in a model is related to the level of analysis at which the engineer is working. Figure 2 illustrates the levels of analysis for a proposed transportation system. Decisions as to mode of transportation for example, are made at the highest or "technology" level; here the mathematical model may be extremely generalized. As the analysis proceeds to lower and more detailed levels the models must become increasingly true-to-life so that the engineer will be able to discriminate between the consequences of one course of action compared with another.

It is in the manipulation of mathematical models that the high-speed computer is the most useful to the would-be decision maker. By quickly and accurately performing the necessary routine calculations, the computer permits the engineer to evaluate and analyze a greater number of alternate solutions in the time available.

Evaluation of the predicted consequences of each alternative is usually done in monetary or economic terms. Though this may not be completely desirable in some cases, it is in keeping with the milieu in which the engineer operates; that is, the original goals are set by executives working within a fixed budget; so comparisons of alternate solutions to the problem must be couched in terms related to money. One phrase used to express the evaluation of an alternate is "measure of effectiveness" (1). In an analysis of highway location, this may be the total annual cost of an individual alternate or it may be a comparative measure such as the benefit-cost ratio.

Once the alternatives are evaluated they are compared with one another and with the original goals. The comparison must be unbiased and must consider the reliability of the data used in reaching this stage of the process. The best alternative may not satisfy the original goal; in this event either the goal must be lowered or the engineering process repeated for a new set of alternatives. If the two best alternatives have measures of effectiveness that are nearly equal the decision may be based on criteria other than the economic.

Figure 3 shows the application of the engineering process to a typical highway location. In this example there is an existing alignment with a measure of effectiveness based on total annual cost. The goal is to find an alignment with a minimum total annual cost that is also less than the status quo. Three alternatives are selected and their location defined in three dimensional coordinate system. A mathematical model is devised for each significant variable and from these the consequences of each alternate are predicted. By assigning a cost to each of the

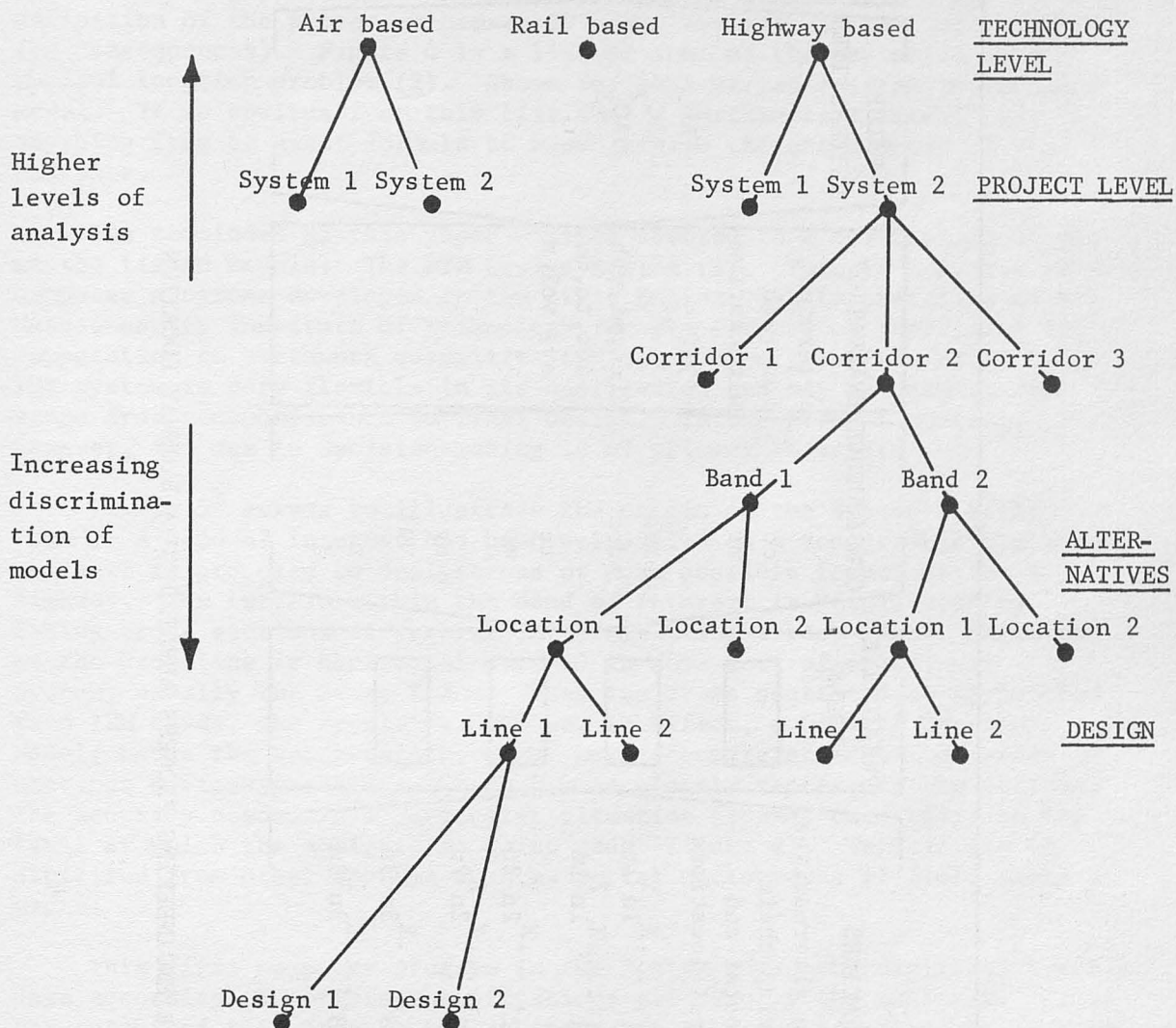


FIGURE 2 - LEVELS OF ANALYSIS

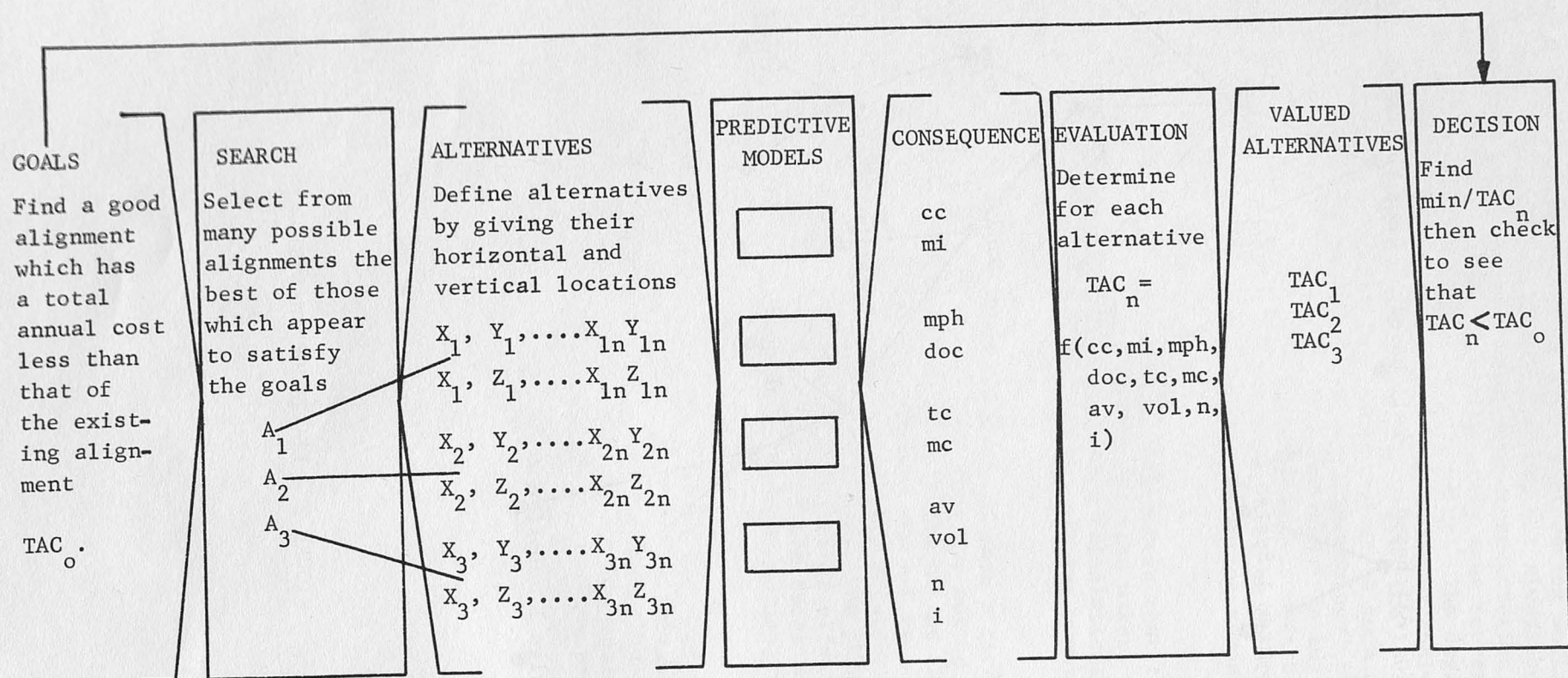


FIGURE 3 - THE ENGINEERING PROCESS APPLIED TO A HIGHWAY LOCATION

consequences, the alternates are valued and a decision is made based on the relative degree to which each alternate satisfies the original goal.

Most of the practical difficulties encountered in applying the decision-making process to a highway location are concerned with the definition of the proper mathematical model for each of the variables (or consequences). Figure 4 is a list of some of the variables in a typical location problem (2). Shown for each variable is an appropriate model. It is obvious from this list that a "mathematical model" may be anything from an exact formula to a subjective thought process of the engineer.

The remainder of this paper will be devoted to a description of one of the listed models: The DTM Design System (3). This is a series of five computer programs developed in the Civil Engineering Laboratories of the Massachusetts Institute of Technology for the Purpose of expediting the computation on earthwork quantities and associated geometric data. The system is very flexible in its application and may be used at any stage from reconnaissance to final design. In the present context, however, its use in decision-making is of primary interest.

Figure 5³ serves to illustrate the origin of the system's title; "DTM". A band of interest has been delineated on a topographic map within which it is proposed to analyze one or more possible locations for a highway. The terrain within the band of interest is "digitized" by taking cross sections at regular intervals along a base line. Position of the base line is horizontal defined in some sort of coordinate system, usually the State Plane. When the cross section data is punched into IBM cards, the resulting deck is, in effect, a Digital Terrain Model; hence the abbreviation, DTM. More accurate and detailed cross sections obviously yield a DTM that more closely represents the terrain. The accuracy needed in a particular situation depends once again on the level at which the analysis is being made (Figure 2). Terrain may be digitized from other sources such as aerial photographs or field measurements.

This first computer program in the System edits the digitized terrain data according to certain specifications selected by the engineer. Using the output of this program the engineer corrects and re-edits the terrain deck until it is error-free.

Figure 6 is a flow chart illustrating the reasoning process behind a typical location analysis. The logic, procedural looping and feedback aspects of the chart are already familiar to most highway engineers.

³Figures 5, 6, 7, 8, and 9 were adapted from reference 3.

FIGURE 4
TABLE OF MATHEMATICAL MODELS

<u>NAME</u>	<u>VARIABLE</u>	<u>MATHEMATICAL MODEL</u>
Earthwork Cost	ec	DTM Design System
Structures Costs	sc	Ky. Department of Highways Bridge Cost
Pavement Costs	pc	Ky. Department of Highways Pavement Cost Data
Drainage Costs	dc	Drainage Design System
Interchange Costs	ic	DTM Design System or Volumetric Quantities Program
Relocation Costs	rc	Volumetric Quantities Program
Land Costs	lc	Zone Cost Evaluation Program
Percentage Vehicles of Class n	k	Ky. Department of Highways Traffic Data
Fuel Cost	fc	Vehicle Simulation and Operating Cost Program
Tire Cost	trc	AASHO "Red Book"*
Oil Cost	oc	AASHO "Red Book"*
Vehicle Maint. Cost	mtc	AASHO "Red Book"*
Depreciation Cost	dpc	AASHO "Red Book"*
Time to Travel Alignment	t	Vehicle Simulation and Operating Cost Program
Unit Time Costs	tc	No Model Available - Engineer's Discretion
Time Unreliability Costs	tur	No Model Available - Engineer's Discretion
ADT Volume	vol	Kentucky Department of Highways Traffic Data
Annual Increase in Traffic	av	Kentucky Department of Highways Traffic Data
Interest Rate	i	No Model Available - Engineer's Discretion
Service Life	n	No Model Available - Engineer's Discretion
Length of Alignment	mi	DTM Location and Design Systems
Maintenance Cost	mc	Kentucky Department of Highways Maintenance Cost Data

*American Association of State Highway Officials, Committee on Planning and Design Policies, Information Report on Road User Benefit Analyses For Highway Improvements, Washington, D.C., 1960.

USING THE SYSTEM FOR HIGHWAY LOCATION

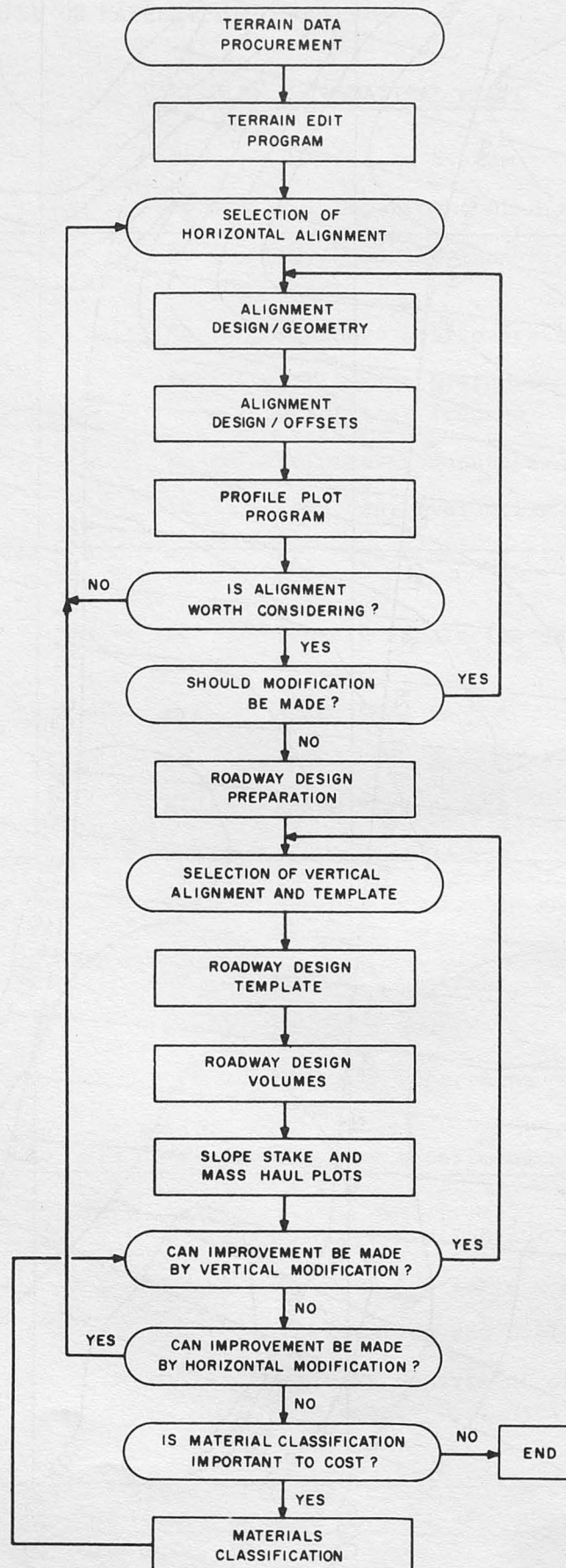


FIGURE 6 - FLOW CHART HIGHWAY LOCATION ANALYSIS

Figure 7 shows this same process as automated in the DTM System. As can be seen, the computer performs only the routine calculations and graphical plotting. The engineer enters the process at critical points that require his judgement; setting of the terrain edit specifications, selection of horizontal and vertical alinement and the design of the cross section or template.

A selected horizontal alinement for the previously described band of interest (Figure 5) is indicated by the heavy line in Figure 8. The alinement is described to the computer in the same way as the base line except that some curve defining parameter (radius, degree of curve, external or tangent) must be specified for each point of intersection.

The Alinement Design Program then computes all the usual curve data and interpolates in the terrain deck to obtain the ground elevations at intervals along the proposed alinement. The elevation and the perpendicular offset from the base line of each point on the center line are punched (as part of the program output) into special "offset cards". This set of cards is then used (with appropriate scale data) as input to the Profile Plot program. The output of this run, when printed on a specially wired machine, produces an accurate ground profile which the engineer uses to design the vertical alinement.

Input for the Roadway Design program includes the vertical alinement (as specified by the station, elevation and length of vertical curve for each intersection of grade lines) and a series of cards setting forth the shape of the template, cut and fill slopes and other necessary design parameters. (Figure 9). Program output consists of the finish grade elevation, slope stake coordinates, station-to-station and cumulative cut or fill and the mass haul ordinate for each station. The slope stake and mass haul data may be graphically represented by a procedure similar to that described for the profile plot.

If rock excavation quantities are to be determined separately a fifth program of the series (Materials Classification) may be employed. Use of this program requires an input of soundings that defines a "rock model" in the same format as the original terrain model. The Materials Classification program can also be used for the complex earthwork computations that often occur at interchanges and at junctions of bifurcated roadways.

Supplied by the computer with the physical consequences of his selection the engineer may now make his evaluation and decide if modifications are required to improve the design (Figure 6). The entire process is then repeated for each alinement selected.

The above describes only one of the mathematical models that have been successfully computerized. Some other programs developed at MIT include those for Volumetric Quantities (borrow pits, channels, etc.)

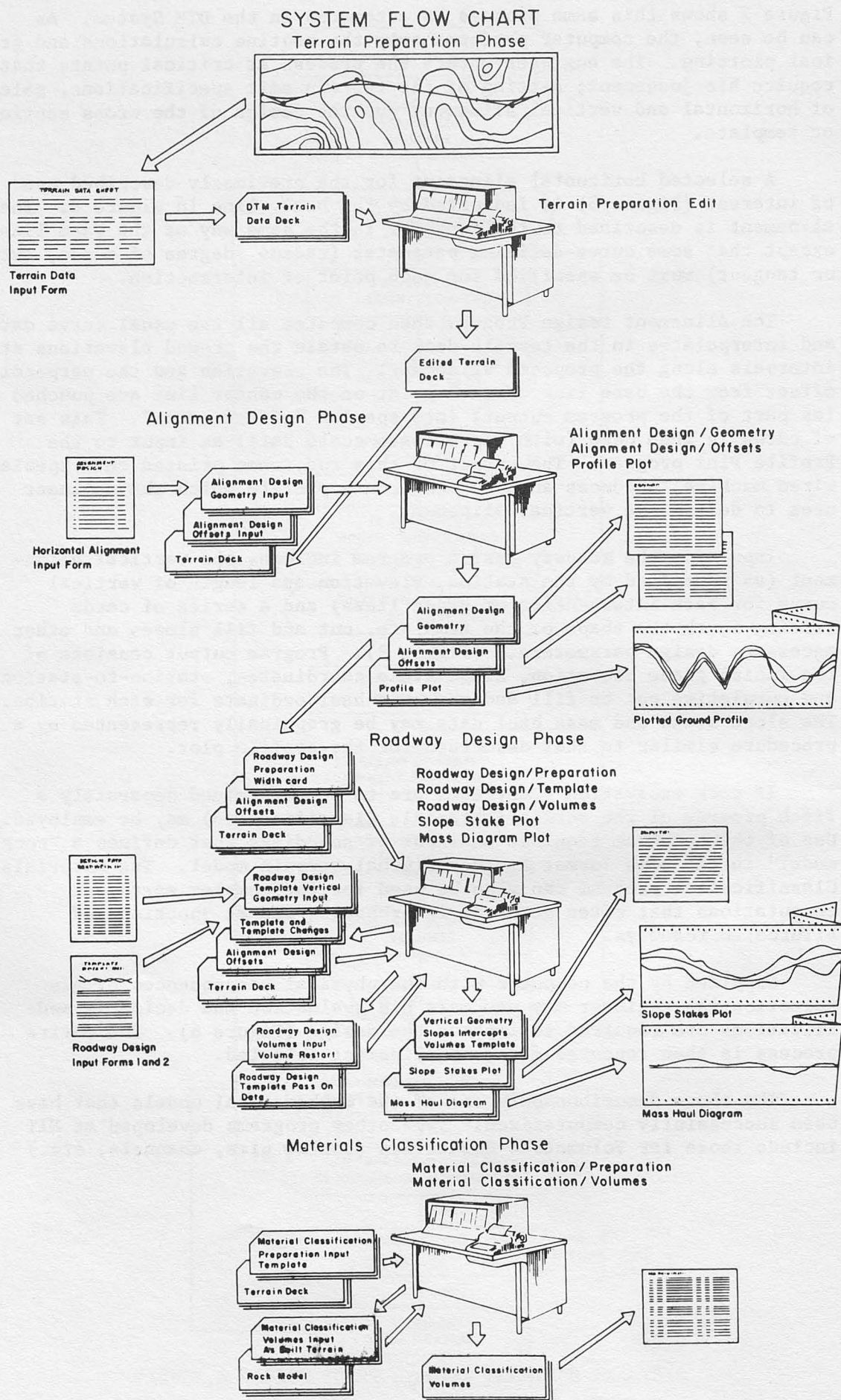


FIGURE 7 - FLOW CHART DTM LOCATION SYSTEM

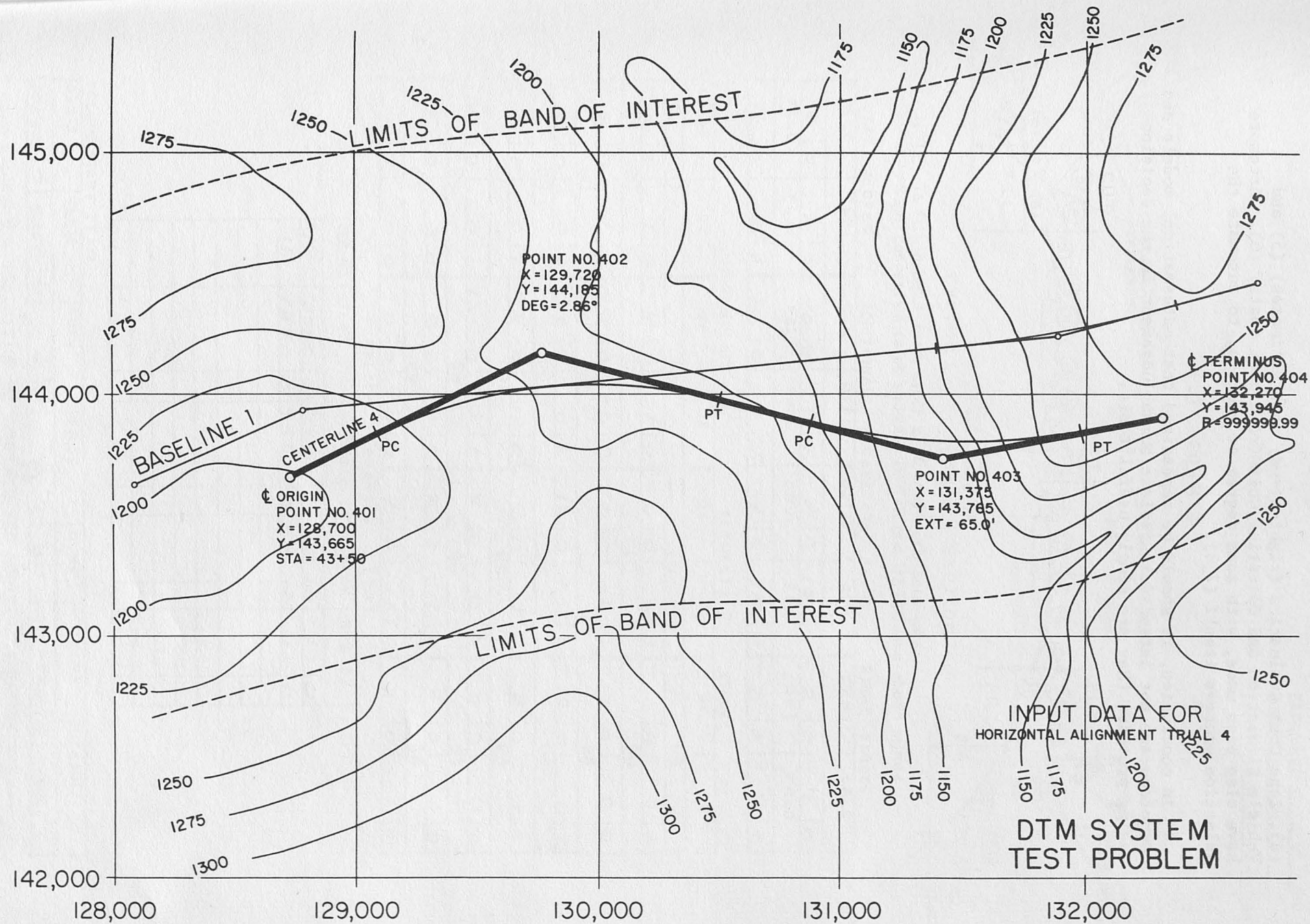


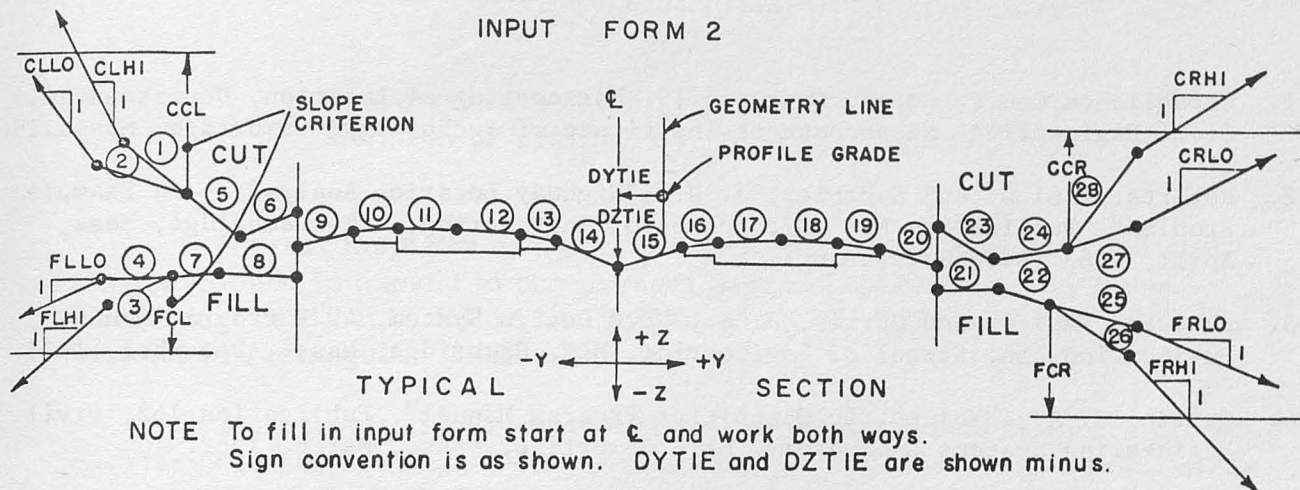
FIGURE 8 - DESIGNATION OF TRIAL ALINEMENT

(4), Zone Cost Evaluation (right-of-way cost estimates) (5) and Vehicle Simulation and Operating Cost (road user costs) (6). Attempts have also been made, with some degree of success, to automate the selection process itself (7,8).

In conclusion, it should be emphasized that mathematical models and computers are not intended to replace human judgement in the decision-making process; they are simply useful tools.

DTM
ROADWAY DESIGN
INPUT FORM 2

ENGINEER PCF JHS
DATE 3/27/62
PROJECT DTM TEST PROJ.



LEFT SLOPES		ADDITIONAL PARAMETERS IT=9				RIGHT SLOPES	
CLLO	CLHI	CCL	DYTIE	DZTIE	CCR	CRHI	CRLO
4 0	2 0	10 0	0 0	- 1 0	10 0	- 2 0	- 4 0
FLLLO	FLHI	FCL	FMUL	CMUL	FCR	FRHI	FRLO
4 0	2 0	10 0	1 25	1 0	10 0	- 2 0	- 4 0

TEMPLATE		SEGMENTS		IT = 7	
DY	DZ	DY	DZ	DY	DZ
(1)	(2)	(3)	(4)	(5)	(6)
- 2 0	1 0	- 4 0	1 0	- 0 0	0 0
(7)	(8)	(9)	(10)	(11)	(12)
- 2 0	1 0	- 2 0	- 1 0	- 0 0	0 0
(13)	(14)	(15)	(16)	(17)	(18)
- 0 0	0 0	- 6 0	- 0 2	- 12 0	- 0 1
(19)	(20)	(21)	(22)	(23)	(24)
- 6 0	0 2	- 4 0	1 0	4 0	1 0
(25)	(26)	(27)	(28)	(29)	(30)
12 0	0 1	12 0	- 0 1	6 0	- 0 2
(31)	(32)	(33)	(34)	(35)	(36)
1 0	0 0	0 0	0 0	2 0	- 1 0
(37)	(38)	(39)	(40)	(41)	(42)
1 0	0 0	0 0	0 0	4 0	1 0

TEMPLATE CHANGES IT=8		IT=8	
SEG. NO.	START STA.	END STA.	NEW DY NEW DZ
14	7350 0	7550 0	- 8 0 1 0
15	7350 0	7550 0	8 0 1 0

VOLUME START IT=12

BLSTA	CLSTA	CUTV	FILLV	CUMC	CUMF	HAUL
10550 0	4350 0	0 0	0 0	315 0	- 420 0	- 105 0

FIGURE 9 - DEFINITION OF TEMPLATE AND ADDITIONAL PARAMETERS

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